DISCUSSION BEFORE THE WIRELESS SECTION, 2ND DECEMBER, 1936

Mr. L. B. Turner: The history of the thermionic valve seems to divide itself into five main epochs. There are the four great successive jumps associated with the names of Edison, Fleming, de Forest, and Langmuir; and there is the fifth period of minute and intricate development. Of this last period the authors have given a delightful survey. If any of us have been disposed—as I think I have—to regard the really important work as finished a quarter of a century ago, we were clearly mistaken. The modern valve is not the old valve with a patch of lime on the cathode, and an additional grid inserted from time to time by a clever glassblower.

On page 67 the term *Inselbildung*, literally "island formation," is (as I think) used rather misleadingly. *Inselbildung* is not *due to* the non-uniformity of electric field; it *is* that non-uniformity. The word is merely a picturesque description, in German, of the obvious condition of field close to the region immediately below a wire of a grid whose potential is negative. There is obviously no emission from a portion of cathode situated there. In general I deprecate the construction of cant terms in wireless literature by the importing of homely foreign words, unless, of course, some gain in clarity results. More familiar examples are the words *ziehen* and *Litz*. It is right in German—but not, I hold, in English—to describe the pulling into step of one oscillator by another as *ziehen*; for *ziehen* simply means "to pull." Again, *Litzdraht* is stranded wire; but why should an Englishman write *Litz*, especially when it is not the stranding, but the separate insulation of the strands, which he wishes to express? This use of *Litz* is on a par with the comic term *bobbine de self*, wherewith a Frenchman thinks he expresses the gist of "self-inductance coil." We in England, knowing the language, prefer the abbreviation, "inductance coil."

Finally, I want to ask the authors for a little more information about the rectilinearity of valve characteristics. In the simple triode, with no complications from secondary emission and with the whole cathode emission passing to the anode, the concave curve of the $\frac{3}{2}$-power law is not merely given a point of inflection as an obvious effect of gradual saturation and so on. Somehow, to a degree that has always puzzled me, the valve maker often provides a magnificent extent of straight line between concavity and convexity. I want to ask the authors whether this is fortuitous; or whether the valve maker strives, empirically or by calculation, to emphasize this feature; and, if so, how he does it.

In the more complicated multi-grid valves, I suppose that grid currents, and especially secondary emissions, largely influence the shapes of the characteristics. A useful valve would be one with two control grids, each of which shows substantially constant transconductance, of value dependent on the potential of the other. Expressed otherwise, if i is the anode current, and e_1, e_2 are the grid potentials, a useful portion of the i/e_1 characteristic is straight—with a slope linearly dependent on e_2. I have encountered only one valve (the Mullard octode FH4) which approaches this condition. I mention the matter in the hope that the authors may be tempted to make some comment on it.

Dr. A. C. Bartlett: I agree with Mr. Turner on the subject of the word *Inselbildung*; I have tried it on quite a number of wireless engineers and I have not found one who knows what it means. Turning to another point of nomenclature, the authors refer to "contaminated-metal emitters." In modern English, "contamination" means that something bad has become mixed up with something good, and that the result is bad. In the case of these so-called contaminated-metal emitters, on the other hand, the thorium is added to the tungsten with great care and the result is good; so that I think "contamination" is not the right word to use. In this same connection the authors mention the use of phosphorus; is not phosphorus used only with the pure tungsten filament? I believe it was the use of magnesium as a getter which made the thoriated tungsten filament a real commercial success.

I am disappointed to find that on page 81 the vapour process is not fully described.

The authors have not yet found a sovereign cure for grid emission, and they still lack full control over screen emission. This fact might serve as an excellent challenge to the other valve-makers to say what they have done in these two fields.

It is interesting to find that the authors do not expect further large-scale progress in the oxide-coated cathode, because most of the valve developments have been due to oxide-cathode progress; for instance, the modern heptodes and hexodes could not be made with the old-type tungsten filament. It is interesting to speculate in what direction progress is to be looked for. If, as the authors say, there is going to be a vast amount of competition between the valve-makers, it would be a very good thing for set-makers, and also for all users of valves, if the valve-makers concentrated their attention on reducing the $\pm$ 40 per cent variation in characteristic, and did not worry so much about getting big increases in conductance. The other developments indicated seem to be in the direction of shorter waves. The authors mention 5 and 6 metres for television, but I understand that American engineers have a television transmitter working at 1·7 metres. In this connection the authors show an acorn valve, and it would be interesting to know what they think of this type, and whether they are going to produce it commercially.

Mr. T. E. Goldup: In referring to screen-grid valves the authors say: "The principal requirement in these valves is that the screen shall reduce the capacitance between anode and control grid to a very low value (0·0001–0·001 $\mu\mu$F)." Should not these figures be 0·001 and 0·01 $\mu\mu$F respectively? We are accustomed in these days to capacitances of the order of 0·003 to 0·005 $\mu\mu$F for valves of this type, and figures below these values are difficult of attainment. Fig. 6 shows a curve of the energy of primary electrons plotted against secondary-emission coefficients, and I should like to ask how one can interpret this in terms of the number of secondary electrons per primary electron. Have the authors any information on the effect of the angle of incidence of various electrodes subjected to primary electron bombardment?

They make reference to the expense involved in valve testing. In the case of the more popular types made in large quantities consistently, I would suggest that it is quite legitimate in the present state of the manufacturing art to test only a very small percentage for complete characteristics, and so control the manufacture from this point of view, and to test the bulk in some simple way giving a measure of actual performance under working conditions. In this way the expense of testing can be kept down to a minimum.

On page 94 there appears the remark: "In this country the main effort of most manufacturers has been to secure the greatest possible degree of efficiency from each valve." Presumably this means that they have arrived at the highest possible conductance. If this is at the expense of other characteristics such as input capacitance, or of valve reliability, then I think it is a most unwise policy. All set designers would like the maximum conductance in any given valve, but there are limits beyond which it becomes impossible for an increase in conductance to result in a comparable increase in gain, conversion or output as the case may be, as this limitation is usually determined by circuit considerations.

The one case where we could with advantage utilize very high conductances is in vision receivers, where, however, we also require the minimum grid-anode capacitance. These two requirements are so linked up with valve design that with our present manufacturing methods a compromise has to be effected.

I am rather worried by the authors' reference to the effect of intensive competition on valve types. There is really no need for the present increase year by year in the number of types of valves; those at present on the market can meet all the application needs likely to arise in connection with broadcast receivers and other valve applications. I would ask valve users to encourage manufacturers to settle down to standard manufacture, which I think will be reflected, as far as the user is concerned, in the price which has ultimately to be paid.

Mr. Harold S. Walker: In a broadcast system there is a large number of valves in cascade, and the problem is therefore quite different from that which confronts the designer of a receiving set. Until a few years ago, the highest required gain in a broadcast amplifier was of the order of 60 db. To-day that gain has been increased to 90 db, and the tendency is for the required amplification to increase to meet the new microphone technique which is at present being employed. Whereas the designer of a receiving set seldom requires voltage amplification greater than about 30 db, the designer of a broadcast amplifier must have valves which have a very low level of noise and microphonicity to meet his much more difficult requirements. We discovered some years ago that the valves which were the most microphonic were as a general rule those which had the lowest level of background noise. I refer in particular to valves such as the LS5 and LS7, which had their insulators completely outside the electron stream. In order to reduce the microphonicity, insulators were brought much nearer to the cathode and mica was used instead of glass. As soon as this was done valve noises began to arise, although the microphonicity was greatly improved. Generally the noise was negligible when the valve was new, but became rapidly worse after a few hundred hours of life. As the authors state, this may in some cases be due to leakage across the insulators, but we hold the theory that a good deal of the noise is due to the insulator itself emitting secondary electrons while under continuous bombardment of primary electrons from the cathode. Accordingly, some years ago we developed, in co-operation with the authors, some valves having steatite insulators, which do not emit secondary electrons, and considerable improvements have resulted from this development. There are probably other ways of getting round the difficulty; for example, I suggest that it is possible to screen the insulators from the electron stream. This might enable mica to be used as an insulator (which is very desirable from the manufacturing point of view), without its attendant troubles due to noise, the great point being to design a valve which not only is quiet at the beginning of its life but remains quiet through several thousand hours of use.

I should like to suggest to the authors and their associates that there should be a little more standardization, particularly in heater voltages and currents. Some years ago we managed to standardize 4 volts for the filaments of valves, particularly those of the indirectly heated type, but in the case of valves recently designed for series running there appears to be no standardization; some manufacturers produce valves taking 0·1 ampere, some 0·25 ampere, others 0·3 ampere, and so on. If we, as the users of valves, agree not to ask the manufacturers for any more complicated types or higher conductances, then they themselves might agree upon a greater degree of standardization in this direction at least.

With regard to the future designs of valves, it is felt that the grid should always be brought out at the top of the valve where there is a choice between bringing out the anode or the grid, and in some triodes, particularly those to be used with alternating current on the heaters, the grid should always be brought out at the top. This practice has many advantages which are well known.

It is not very difficult in these days to introduce the feed-back principle, and this is particularly applicable to the output stage of a receiver or amplifier, particularly those of the better type. By this means it is possible to reduce the harmonic content of the output stage very considerably, and this suggestion opens up a field for the better use of pentode output valves. I also think that the present output triodes could be improved, and suggest to the authors that there is a demand for an indirectly heated triode working on a high anode voltage.

I must join issue with the authors in regard to their symbols for indicating the parameters of valves. The following symbols have been standardized in this country: Amplification factor, μ; anode impedance, r_a; mutual conductance g_m. It would, I think be particularly desirable to use these national symbols more extensively.

Dr. K. R. Sturley: The authors give 0·5 megohm as the impedance of a coil working at 1 000 to 1 500 kc; surely 0·1 to 0·15 megohm would be a more correct value for the majority of broadcast receivers. They also

refer to the discovery of thermionic emission from the electric lamp. In this connection it is of interest to note that, 10 years before Edison observed the effect, Guthrie described* how he had taken a charged ball heated to dull red heat, and found that it discharged a negatively-charged electroscope, and how if it was heated to bright red heat it discharged a positively- or negatively-charged electroscope. This indicated the presence of positive ions and electrons. Other valve manufacturers have observed the poisoning effect of putting a positive voltage between cathode and heater. My own experience indicated a tendency, in certain valves, to drift back to the original conditions; the improvement was not always maintained. Furthermore, the sudden application of a d.c. voltage resulted in a large leakage value which was very quickly reduced to normal. This suggests that from an alternating-current point of view leakage may not be the same as from a direct-current point of view, and it is necessary to be careful in assessing the leakage in terms of d.c. voltage.

I am particularly interested in the question of hum, and agree with the authors' description of how hum is produced. I have noticed, however, that the most unpleasant form of hum seems to occur when the grid is negative with respect to the heater (which does not mean that it is necessarily negative with respect to the cathode). This effect is probably due to positive ions. Examination on the cathode-ray oscillograph showed a very decided peak in the 50-cycle wave just on the peak of the negative half-cycle. Another source of hum was rectification between heater and cathode, and this was particularly unpleasant in frequency-changers using cathode injection. The high-frequency voltage of the cathode circuit and the a.c. voltage between cathode and heater are in series, and the heater acts as a detector producing modulation of the high-frequency wave by the 50-cycle supply. This effect can be eliminated by connecting a condenser of $0 \cdot 001\ \mu F$ between heater and cathode. A further effect, not referred to in the paper, which I have noticed, is modulation of a tuned circuit in the grid of a valve. This is presumably due to magnetic control of the space charge by the heater current.

The authors suggest that the greatest difficulties are microphony, leakage, and inter-electrode capacitance in the "pinch," and they refer in that connection to the ring seal. I should be interested to know whether there is a possibility of the use of the ring seal being explored. The present form of pinch has been in operation at least since the end of the War, and has not progressed very far.

The paper would have been more complete had the authors referred to developments beyond the confines of this country. There have been considerable improvements, for example, in American practice; there is the American beam valve and the all-metal valve. There is also a Danish valve which operates on the cathode-ray principle.

Mr. F. D. Goodchild: With reference to the paragraph in the paper on oxide emitters, I think it was in 1914, not 1920, when oxide-coated filaments were first applied commercially; valves having oxide-coated filaments were used by the Bell system in their repeater circuits in 1914, and numbers of valves with such filaments were made during the War years in the United States. In view of the rapid rate of progress in the radio industry, it is surprising that it was not until the later 'twenties that the use of oxide-coated filaments—a simple device—became general. The delay is probably due to the large amount of attention which was given to thoriated tungsten filaments.

Fig. 46 shows the heaters used in indirectly-heated cathode tubes; it seems to me that with so much of the core exposed the tungsten must reach an elevated temperature and so increase the danger of recrystallization. In broadcast receivers designed for use on either a.c. or d.c. supplies the rectifier heater has to be designed to withstand a peak approaching 700 volts, in which case it seems to me that the exposed core is not satisfactory. This heating can be practically eliminated by the use of a coating material which has been pre-shrunk to a maximum possible density before applying it to the wire, and then applying it in 10 or 12 coats, each coat being sintered at 1 800° C. after it is applied. I have found that it is not sufficient merely to test the heater in a circuit which switches the current on and off several times a day. Some heater failures in radio receivers are undoubtedly due to mechanical vibration coming from the loud-speaker. I therefore mount indirectly-heated valves on panels of sheet iron in the centre of which is an electromagnet, fed from a beat-frequency oscillator, whose frequency is continuously varied through the audible range. This system has caused the failure of valves which have successfully withstood the switching test for many months.

Dr. R. L. Smith-Rose: It is gratifying to learn from this paper that a certain amount of fundamental research on the development of valves is being conducted in the works and research laboratories of the country, because from time to time one hears the question raised as to whether the whole of modern valve development work is not taking place abroad, and this thought crossed my mind on reading the earlier portion of the paper. Looking back over the history of the valve, it appears that, although Fleming produced the first diode, the third electrode was introduced in America, the fourth in Germany, and the fifth in Holland. There is thus some basis for the suggestion that this country is not holding its own in this type of valve research, and this feeling is confirmed on looking through the References given at the end of the paper. I take it that these comprise a typical selection of papers dealing with the development of valves. Of the 42 references given, 30 are to work that has been published in foreign journals or to British patents taken out by non-British patentees. Of the remaining 12 publications, 9 emanate from the General Electric Company's laboratory! It may be, however, that there is a good deal of research going on in this country which is not published and may not be suitable for publication.

As a result of reading this paper I now have a good deal more respect for the manufacturer than I had before. I had not realized, for example, the great importance of such accurate dimensioning of the valve as is indicated on page 74. I am appalled by the possible necessity

* *Philosophical Magazine*, 1873, vol. 46, p. 257.

of having to maintain an accuracy of 1 per cent in the dimensions of the "acorn" valve.

I endorse Mr. Turner's remarks on the question of nomenclature. It seems that we have to import from abroad not only the valves but the terms with which to describe their operation! It should not be beyond the ingenuity of those carrying out research to produce British counterparts of these foreign expressions.

I should like to inquire as to the present position regarding the metal type of receiving valve, because this was one of the cases where this country took a lead. I am thinking of the "Catkin," which came out at quite an early date but for some reason did not seem to reach the commercial stage satisfactorily. Since then such valves have been produced on a commercial scale in America.

The final suggestion that I have to make refers to future development, and is that there is a big and growing demand for better valves for use on ultra-short wavelengths. The acorn valve is not necessarily the final solution, and it is not necessary to resort to such a form of construction for wavelengths down to 1·5 or 2 m. There is a demand for a valve with a good performance on normal ultra-short wavelengths of between 2 and 10 m. It is very desirable that manufacturers should give their attention to the study of such problems.

Mr. E. B. Moullin: On page 70 the authors say: "Most of the secondary electrons possess low initial velocities. . . ." Does "low" mean "small compared with the initial velocities to which we are accustomed from a cathode"? I have been able to find little information on this subject, except in one paper by Barber* and another by Sharman;† and according to these writers the most probable velocity is usually of the order of about 4 volts, which is very high indeed compared with the 0·1 or 0·2 volt which we associate with a hot cathode. I should like to see some specific information about these velocities included in the present paper; this would complete the information given in Fig. 6.

Mr. J. P. Harvey: With regard to the measurement of the conversion conductance of pentagrids, the authors state that there are two methods, the low-frequency (50-cycle) a.c. method and the high-frequency method, and they seem to imply that the latter is not quite so accurate as the former. I should like to have their comments on this point, and also any remarks they care to make on the theory of the low-frequency method which they put forward; it does not seem to line up with the high-frequency method of measurement.

Mr. A. J. Gill: I am rather disappointed that so little reference is made in the paper to the subject of valve life. On page 88, under "Electrical Life," the authors say: "Where very long lives (20 000 hours and more) are required, as in valves for use in P.O. telephone repeater circuits, low-temperature operation of the cathode is essential." Not much is said about the possibility of increased life for the ordinary wireless valve, a matter of greatly increasing importance at the present time. In actual practice, we find that some of these valves may have an efficient emission life of anything from 100 hours to 2 000 or 4 000 hours. A commercial wireless receiver may have as many as 30 valves in it, and if each lasts 100 hours it will be necessary to replace each valve 87 times in the year, so that over 2 000 valves will have to be replaced on that receiver every year, which at 10s. each means over £1 000 a year. On the other hand, if one can get a life of 1 000 hours the cost of valve replacements will be about £100 a year. The annual cost of runnning a commercial wireless receiver on a 24-hours-per-day basis lies between £100 and £1 000. One would therefore very much like to see an improved life for some of these valves.

Another point is that the ordinary broadcast receiver has hitherto generally employed 3 or 4 valves, but now television receivers are being introduced having up to 20 or even 30 valves. Although these receivers are not used for many hours each day, the valve consumption may be fairly high, while the cost of locating and remedying the fault greatly exceeds the valve cost. I think the valve manufacturers ought to supply a valve which will last as long as the wireless set; there is no reason why it should not be built into the set.

Finally, I think there are only two voltages which should be standardized: 4 volts and 240 volts. It is time an ordinary valve was made in this country to run off the electric light mains.

Mr. B. Drake (*communicated*): I think it is generally admitted that equations (3) and (4) on page 67 are too complicated for general use. Apart from this, these equations only apply to a cylindrical system of electrodes. In practice no modern triode or multi-grid valve can be assumed to be a cylindrical system as the backbone wires supporting the grids prevent the electrons from radiating out in all directions, and, in fact, tend to focus them into two streams at right angles to the plane containing the support wires, as shown in Fig. 8 (page 70). Again, if the turns of the grid helix are closed up so that they actually touch one another, then $n = 1/\rho$, and according to (4) the value of μ, although large, will still be finite, whereas it should actually become infinite, because there now remain no spaces between the turns through which the anode field may penetrate to the grid-cathode space.

In view of the foregoing I have searched for an empirical formula which can be worked out with a slide rule and will give results in fair agreement with actual values found in practice. Such a formula is given below:—

$$\mu = \frac{50}{k} \cdot \frac{s\rho}{P^2 - \rho^2}$$

where s = grid-to-anode distance; ρ = grid-wire diameter; P = pitch of grid helix; and k = spread factor. The factor k depends upon the amount the beam of electrons spreads out between grid and anode. With flat electrodes the beam is straight and $k = 1$, but with cylindrical electrodes the beam usually spreads out and k is greater than unity. When ρ^2 is small compared with P^2 the formula becomes of the type given at the top of page 91, this form being particularly useful for adjusting the grid pitch in order to make small corrections to the amplification factor. Table A gives a comparison of values of μ calculated from the above formula (assuming $k = 1$) against actual values. The

* *Physical Review*, 1921, vol. 17, p. 322.
† *Proceedings of the Cambridge Philosophical Society*, 1927, vol. 23, pp. 523, 922.

agreement is quite good except for the HL2 valve, in which the central part of the filament is held close to the grid backbone supporting wires by insulated hooks, and for the A537, in which the calculated value is high owing to the spreading-out of the electron beam.

The loss of mutual conductance at wide grid pitches (see Fig. 3) is stated to be caused by the phenomenon referred to in the paper as *Inselbildung*, i.e. the non-uniformity of the electric field in the neighbourhood of the cathode surface. I should like to put forward additional reasons for this loss of mutual conductance. For purposes of calculation a triode can be replaced by an equivalent hypothetical diode whose anode voltage is

$$\frac{V_a + \mu(V_g + v)}{1 + \mu}$$

Comparing equation (5) with equation (1), it will be seen that the radius of the anode of this hypothetical diode has been assumed to be the radius of the grid (b). I question this assumption. Should not the radius be rather $a + \mu b/(1 + \mu)$, so that as $\mu \rightarrow \infty$ the radius tends to that of the grid (b), and as $\mu \rightarrow 0$ the radius tends to that of the anode (a)? Again, if the grid-voltage/anode-current curve for a triode be drawn for a given anode voltage and the origin shifted to the foot of the curve as shown at (1), Fig. A, the resulting curve will be represented by

$$i = k_s\left[\frac{\mu}{1 + \mu}V_g\right]^{\frac{3}{2}}$$

where the space-charge factor (k_s) is given by

$$k_s = \frac{1 \cdot 47 \times 10^{-5} l}{\left(\frac{a + \mu b}{1 + \mu}\right)\beta^2}$$

Thus it will be seen that the current i for a given value of V_g depends on the value of μ, and will be decreased in value as the number of grid turns, and hence the value of μ, is decreased, owing to both the space-charge factor k_s and the voltage factor $\left(\frac{\mu}{1 + \mu}V_g\right)^{\frac{3}{2}}$ becoming smaller. Curves (2) and (3), Fig. A, represent the resulting curves for successively larger values of grid pitch, and it will be seen that the mutual conductance for a given value of i will decrease as the pitch increases.

Table A

COMPARISON OF CALCULATED AND ACTUAL AMPLIFICATION FACTOR

Valve	Anode*	Grid and cathode*	s (corrected for anode ribs	ρ	P	$50\frac{s^2}{P^2-\rho^2}$	Actual μ value
			mm.	mm.			
H30	5·5 2ribs(2×1)	1·9int.	2·0	0·11	0·386	80	80
PX4	5·6 4ribs(3×1)	2·0int.	2·0	0·15	1·66	5·5	5·5
PX25	6·0 4ribs(3×1½)	2·0int.	2·2	0·15	1·26	10·5	9·5
HL2	3·7 3ribs(1×½)	0·8int.	1·5	0·15	0·71	23·5	27
L21	3·7 3ribs(1×½)	0·8int.	1·5	0·15	0·82	17	16
MH4	4·4 2ribs(1½×¾)	2·1int.	1·2	0·15	0·525	36	40
ML4	4·4 2ribs(1½×¾)	2·1int.	1·2	0·15	0·825	13·5	12
A537	5·5 int.dia.	1·4int.	2·0	0·075	0·6	21	15·5

* Dimensions in millimetres.

Equation (1) on page 66 of the paper was fairly satisfactory for most old types of valves where the radius of the anode was more than 10 times the radius of the cathode, for under these circumstances the value of β^2 is approximately unity; so that the current i for a given value of V_a is inversely proportional to the radius of the anode a and is independent of the radius or

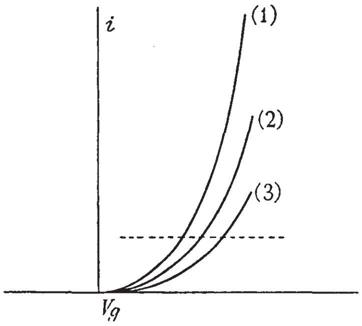

Fig. A

shape of cross-section of the cathode. This will not hold, however, for modern closely-spaced electrodes where a may be only $1\frac{1}{2}$ times c; but it will be seen from Table B that $1/(a\beta^2) \simeq a/d^2$ for all values of a/c, where d is the cathode-to-anode distance $(a - c)$, and hence instead of (1) we may write the approximate equivalent equation

$$i = \frac{Kal}{d^2} V_a^{\frac{3}{2}}$$

Thus we see that the current for a given value of V_a is proportional to the radius of the anode and inversely

Table B

a/c	$1/(a\beta^2)$	a/d^2
1·25	$18\frac{1}{c}$	$20\frac{1}{c}$
1·5	$5{\cdot}7\frac{1}{c}$	$6\frac{1}{c}$
2·0	$1{\cdot}8\frac{1}{c}$	$2\frac{1}{c}$
5	$0{\cdot}26\frac{1}{c}$	$0{\cdot}31\frac{1}{c}$
10	$0{\cdot}102\frac{1}{c}$	$0{\cdot}124\frac{1}{c}$
100	$0{\cdot}0094\frac{1}{c}$	$0{\cdot}0102\frac{1}{c}$

proportional to the square of the cathode-to-anode distance. This, of course, also applies to the triode if it is regarded as a hypothetical diode.

In connection with Fig. 12, I should like to put forward a method of considering the paths of electrons in a valve. We can represent the potential along a line in a valve by a graph such as that of Fig. 12, and similarly we can represent the potential over a cross-section by an inclined surface down which we can imagine balls, representing the electrons, as rolling. A vertical section of such a potential surface is given by Fig. 12 when turned upside down. The potential surface for a tetrode will be represented by a low ridge close to the cathode caused by the intense space charge there, this ridge having slightly higher bumps opposite the grid wires. The ball representing an electron emitted from the cathode with sufficient velocity will roll over this small ridge, otherwise it will return again to the cathode. From the top of this ridge there will be a gentle incline down to the line of the control grid. The negatively charged control-grid wires will be represented by steep hills rising to a higher level than that of the cathode. The ball will pass between these hills, probably being slightly deflected out of its original course by them. On the other side it will encounter a steep gradient down to the positively charged screen. This will accelerate the ball and straighten out its course. The screen wires will be represented by depressions; and if an electron ball is heading straight for a screen wire it will be caught, and the secondary electrons knocked off will fall again into the depression, assuming the anode to be at a lower voltage than the screen. If the ball is not going straight towards a screen wire it will be deflected out of its course by the depression in a similar manner to that of a comet passing near the sun. This deflection of the electrons is the cause of the dispersion at the screen mentioned in the paper on page 71; and will be least for small screen pitches where the depressions will be shallowest. On the opposite side of the screen the ball will encounter a rising slope up to the anode and it will have to pass over a small hump before finally reaching it. This hump is caused by the intensity of the space charge due to the slowed-up primary electrons which have become crowded together, and the proximity of secondary electrons from the anode. These secondary electrons, which are knocked off from the anode with only a fraction of the velocity of the primary electrons, are unable to climb back over the potential hump and either roll back to the anode, or, if they have been shot off obliquely, may skirt around this hump and find a straight slope down to the screen at the side, if the precautions mentioned in the paper have not been taken to prevent this.

It is stated at the top of page 87 that the use of high-frequency induction heating is to remove adsorbed gas. Surely another just as important effect is that the gas in the bulb is heated by convection currents so that its pressure is increased and the pumping speeded up.

Dr. M. Benjamin, Mr. C. W. Cosgrove, and **Mr. G. W. Warren** (*in reply*): We are in agreement with the remarks of several speakers on the desirability of standardization, limitation in the number of valve types, and reduction in the variation of characteristics. This last factor depends to a large extent on the first two, and there is no doubt that receiver designers will obtain a more uniform product when they cease to ask for higher values of mutual conductance. We cannot agree with Mr. Goldup that it is only necessary to test a very small percentage of valves for complete characteristics. While sample testing is sufficient to determine the general quality of a product and the mean value of the various characteristics, it is obviously necessary to test every valve for those characteristics to which definite limits

are set, so that any valves, however small the percentage, which fall outside those limits, shall be rejected.

The rectilinearity of the characteristics of certain triode valves to which Mr. Turner refers is largely fortuitous. A 3/2-power law characteristic approximates to a straight line over a considerable fraction of its length, and voltage saturation of the emission from the ends of the cathode makes this approximation even closer, particularly in power output valves in which the space current is an appreciable fraction of the total emission from the cathode. The production of a valve with two control grids, each of which shows a substantially constant transconductance, has been an objective of probably most manufacturers for some time, and some of the modern hexodes and heptodes do, in fact, approach this condition. The main difficulty is to maintain the transconductance at a constant value at low values of anode current where the curvature of the 3/2-power-law characteristic and the effect of the initial velocities of the electrons are greatest. We are not prepared to give an opinion on the relative merits of particular valve types in this respect.

The empirical formula for the amplification factor of a triode which Mr. Drake gives in his communication is interesting, and Table A certainly shows close agreement between calculated and measured values of μ. Referring to Fig. 3, it is true that the whole of the loss in mutual conductance in the valves which have wide grid pitches is not due to *Inselbildung*, and that from theoretical considerations we should expect the anode current and mutual conductance to depend on the amplification factor. While the formulae for anode current (i) and space-charge factor (k_s) given by Mr. Drake are more accurate than the simpler expressions given in the paper, to which in fact they approximate in practical cases for $\mu > 8$, they do not agree with the results shown in Fig. 3, and there are several additional factors, including the effect of the space charge itself on the characteristics, which should be considered. This has formed the subject of an investigation by one of us (Mr. Warren), and it is hoped to publish the results in the near future. Referring to the measurement of the conversion conductance of frequency-changers, it is not implied in the paper, as Mr. Harvey suggests, that the high-frequency method is less accurate than the low-frequency method. The statement made on page 94 is "This method, though more rapid than the low-frequency test, suffers from the disadvantage that it is not absolute and frequent calibration is necessary." The subject has been discussed in more detail in a paper by Stewart.*

We cannot agree with Mr. Gill's statement that a greater life for the ordinary wireless valve "is a matter of greatly increasing importance at the present time." While it is true that the emission life of valves may vary between 100 and 4 000 hours (much greater lives are frequently obtained) the actual percentage of modern valves in common use which have lives of less than 500 hours is negligible. The argument that if a receiver has 30 valves in it and that if each lasts 100 hours, over 2 000 valves will need replacing in that receiver every year, is meaningless, since the probability of such an event is of the order 10^{-3000}. We imagine that the actual valve-replacement cost met in practice would show the average life of a receiving valve to be very much greater than 1 000 hours, and most valves do, in fact, outlive the receivers in which they are put.

We have not encountered the difficulties which Mr. Goodchild suggests might be expected with the bead form of heater insulator, although we agree that this method of preventing broken filaments is not ideal. Where a hairpin filament is used, however, our experience has shown that the use of a coating material which has been pre-shrunk to a maximum density leads to a far greater percentage of filament failures than the bead form of coating, since in the latter case the heater and coating are free to expand and contract independently. Vibration tests are undoubtedly desirable and it has been the practice, in the organization which we represent, to life-test some valves under vibration conditions. We appreciate the essential difference between the a.c. and the d.c. method of measuring leakage referred to by Dr. Sturley, but our experience has been that the results of the two methods can be correlated, and the d.c. test is more convenient. We have not observed the tendency for leakage currents to reappear after the conduction of the coating has been poisoned in the way described, and we suggest that where this does occur the "leakage" may be thermionic emission between the heater and cathode.

Several of the questions refer to secondary emission. By secondary-emission coefficient is meant the ratio of the number of secondary electrons emitted to the number of primary electrons striking the electrode. A satisfactory account of the effect of the angle of incidence of the primary electrons has been given only since the present paper was written. Bruining* has shown that, in general, the secondary-emission coefficient increases with the obliquity of the primary electrons. Mr. Moullin's remarks on the initial velocities of secondary electrons are correct. By "low initial velocities" we meant velocities which are small, though not negligible, compared with the velocity acquired by an electron in falling through a potential difference normally existing between the screen-grid and cathode. The secondary electrons have, however, a wide energy distribution ranging from zero to the energy of the primary electrons. Thus Haworth has shown† that, for molybdenum bombarded with 150-volt electrons, though the most probable energy of the secondaries is about 3 volts, about 50 per cent have energies greater than 10 volts, and 16 per cent have energies greater than 30 volts. These figures are not directly applicable to the problem of determining the secondary-electron current in a valve when the potential distribution is given. For example, in a system of plane parallel electrodes, it is the normal component of energy which determines whether an electron from the anode will reach the screen, and the normal components of energy are necessarily considerably lower than the total energies.‡

Mr. Walker's view that a good deal of noise in valves is due to secondary emission from mica insulators is interesting, and there is no doubt that the insulators can emit secondary electrons. As explained in the paper, a given point in the insulator can assume either zero

* *Journal I.E.E.*, 1935, vol. 76, p. 227; and *Proceedings of the Wireless Section*, 1935, vol. 10, p. 8.

* *Physica*, 1936, vol. 3, p. 1046.
† *Physical Review*, 1935, vol. 48, p. 88.
‡ L. R. G. TRELOAR: *Nature*, 1936, vol. 137, p. 579.

or some high positive potential depending on the secondary-emission properties and insulation resistance of the insulator and the space charge in the neighbourhood of the point. There must, therefore, be some discontinuity or very steep potential gradient on the surface of the insulator somewhere between the control-grid and anode supports. If the position of this discontinuity moves, one will expect noise. It is, however, difficult to decide whether this factor or variable leakage is mainly responsible for noise. In the first place, the secondary currents depend to some extent on the leakage, and secondly, in a valve with metal shields such as Mr. Walker suggests, these shields, while preventing secondary emission, will also prevent the deposition on the insulator of barium from the cathode, and thus reduce the surface leakage.

We agree with Dr. Sturley that the impedance of the majority of coils used in broadcast receivers may be only 0·1 to 0·15 megohm, but the valve maker must remember that any one of his valves may be required to operate with circuits which do exist having impedances of up to 0·5 megohm. The valves must therefore be designed on the basis of this higher figure.

Several speakers refer to the acorn valve, and Dr. Smith-Rose mentions the demand for valves with a good performance at wavelengths between 2 and 10 metres. This problem is receiving considerable attention, and the acorn valve, which is now being produced in this country, may not necessarily be the best solution.

The difficulties inherent in the design of an indirectly-heated output triode are mentioned in the paper. There is no doubt that a demand exists for such a valve, and improvements in manufacturing technique have increased the possibility of making such a valve. The feed-back principle applied to output stages does, of course, remove some of the disadvantages of the pentode.

The ring seal has recently been used more and more in transmitting valves, particularly those designed for short waves, but up to the present its adoption in receiving valves has been limited on account of the changes in manufacturing technique involved and the capping difficulties, and also because with the modern practice of bringing the grid lead to the top of the valve the standard form of pinch is satisfactory.

The metal valve recently produced in America differs in many essential features from the valves introduced in this country a few years ago under the registered trademark " Catkin." In the latter the anode formed part of the envelope, whereas the American metal valve is simply a standard electrode system in a metal envelope. It does not appear that the manufacture of metal valves, particularly of the air-cooled anode type, can be carried out as economically as that of glass valves, while new types are continually being introduced, owing to the less flexible nature of the plant required for metal valves.

We did not refer in great detail to the vapour process, since this method of producing a dull-emitting cathode is almost obsolete, and is not likely to be revived. The " beam valve " was not referred to as such, although the principle was mentioned in Fig. 9. The additional feature of the beam valve, namely the aligned grids, is not novel, but manufacturing difficulties had prevented the adoption of this feature until recently. Other omissions from the paper were due to our desire to keep it within a reasonable length.

Several speakers refer in the early part of the discussion to the importation of foreign words into the English language. We do not think it desirable to lay down any hard-and-fast principles on this subject. The words *Durchgriff* and *Ruckgriff*, for example, express particular electrical properties of systems of electrodes for which there are no convenient expressions in English. Other words, such as *Inselbildung*, have been adopted as the result of common usage amongst valve engineers. The international nature of science is likely, we suspect, to increase rather than decrease the number of such words. Dr. Bartlett refers to the use of the expression " contaminated-metal emitters "; this is perhaps an unfortunate expression, and might be misleading if taken out of its context. " Foreign-layer emitters " is perhaps a more suitable alternative, but it is, we think, too late to suggest this change since " contaminated-metal emitters " has already been generally accepted, and appears in Reimann's book.* We have resisted the temptation to suggest *schichtkathoden !*

We wish to thank Mr. Goldup for pointing out the error in the values given in the advance copies for the anode-grid capacitance of screen-grid valves. This has been corrected for the *Journal*.

In regard to Dr. Bartlett's comments on the use of phosphorus as a getter, this getter was used in many bright-emitter valves, but he is correct when he says that it was the use of magnesium as a getter which made the thoriated tungsten filament a real commercial success. We also wish to thank Mr. Goodchild for pointing out that the oxide-coated cathode was used commercially as early as 1914. We believe, however, that the first published work on the subject appeared in 1920.†

We are in agreement with Mr. Walker's criticism of some of the symbols used in the advance copies of the paper, and have taken the opportunity of altering these throughout to conform with those in the British Standard Glossary.‡

* " Thermionic Emission " (Chapman and Hall, 1934).
† H. D. Arnold: *Physical Review*, 1920, vol. 16, p. 70.
‡ B.S.S. No. 205, Nov., 1936, p. 249.